Booster Corrector System Specification

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Existing System

The Fermilab Booster includes corrector packages in each of the 48 sub periods. Each corrector package includes:

- ?? Horizontal trim
- ?? Vertical trim
- ?? Quadrupole
- ?? Skew Quadrupole

The dipole trim for which the sub period in question is a high-beta region has a ramped controller, while the other one has a DC setting. That is

- ?? Short straights: Horizontal ramped, Vertical DC
- ?? Long straights: Vertical ramped, Horizontal DC

Each type of quadrupole has an individual DC offset to which is added a ramped current common to one quarter of the ring (although operationally, all four quadrants have identical ramps).

The existing system cannot be run hard enough to adequately control beam position or tune through the cycle without overheating.

The sextupoles are in separate packages. They are bussed in two families with different magnet designs, 12 horizontal sextupoles (SEXTS) and 9 vertical sextupoles (SEXTL). These have adequate strength, but consolidating them in the same package with the other trims would free up space for other devices.

Requirements

Position

Figure 1a shows the beam position at all points around the ring, at roughly 5 millisecond intervals throughout the acceleration relative to the position at injection. Because the tuned injection orbit represents the optimum beam position, this plot would ideally be flat. Unfortunately the existing corrector system is only capable of moving the beam a few millimeters at high field. Figure 1b shows one of the most extreme cases of motion throughout the cycle.

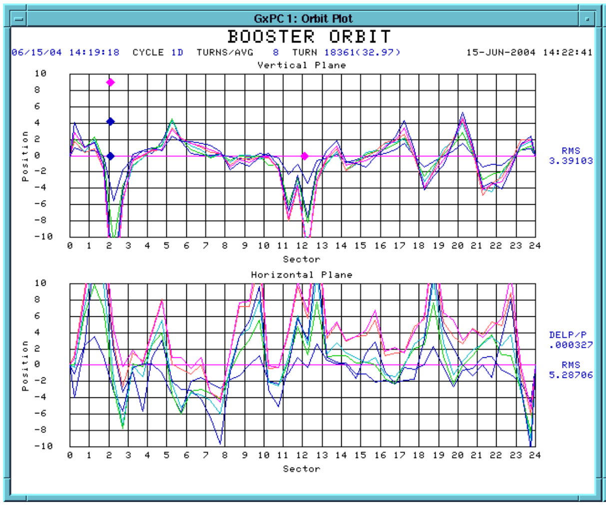

Fig. 1a

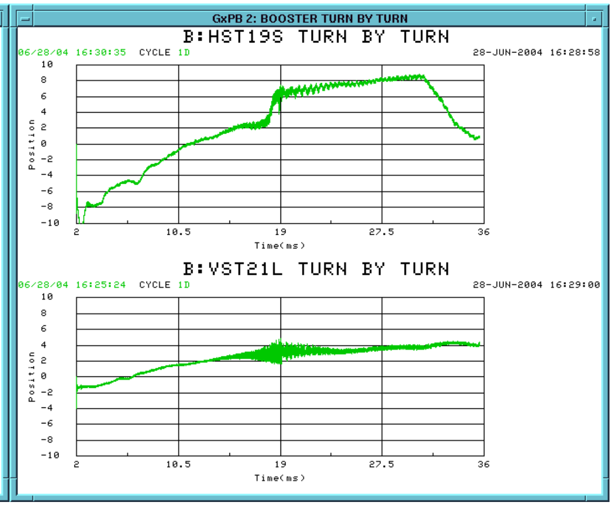

Fig. 1b

It appears from these pictures that a reasonable specification would be 1 cm of beam motion at high field and a slew rate of 1mm/ms up to the middle of the cycle.

Tune

Figure 2 shows the horizontal and vertical tunes throughout the cycle. In addition to being able to stabilize the tunes, we have considered halo removal schemes in which we shift the tune near a resonance in one plane or the other.

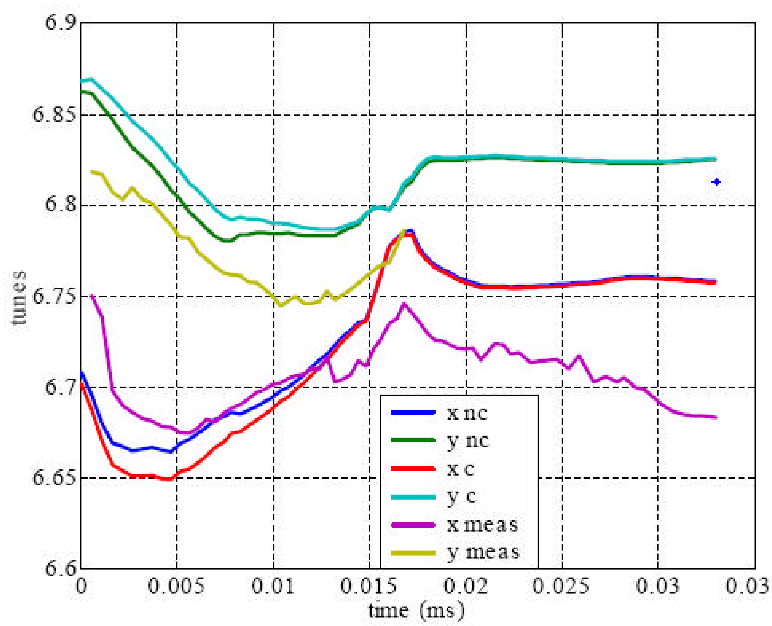

Figure 2: calculated and measured tunes

From this, it appears that a reasonable specification would be ±0.1 tune control at the high field, with a 0.01 unit/ms maximum slewing rate at all energies.

Physical Specifications

The basis for these specifications is presented here. The results are summarized in table 1.

Trim Dipoles

The majority of the beam motion is controlled at the high-β regions. The maximum horizontal and vertical β are 33 m and 20 m respectively. There are roughly 100 degrees of phase advance between high-β regions in both planes. The maximum bend angle needed to make a specified lateral deflection in a three-bump occurs at the end correctors and is given by:

$$\Delta x_2 = \theta_1\sqrt{\beta_1\beta_2}\sin\psi_{12} \approx \theta_{max}\beta_{max}\sin\psi_{period}$$

So a maximum deflection of 1cm would require bend angles of

- 0.3 mrad in the horizontal plane
- 0.5 mrad in the vertical plane

The top momentum in the Booster is about 9 GeV/c, at which these angles correspond to 0.009 and 0.015 T-m respectively. The specification of 1 mm/ms up to roughly half way through the cycle corresponds to about 0.5 and 0.8 T-m/s, respectively.

Quadrupoles

The quadrupoles are driven by the requirement that the system be able induce a 0.1 unit tune shift at the highest fields. This will take a higher field for the lower-β vertical plane. Using the formula

$$\Delta\nu = N \cdot \frac{1}{4\pi}\frac{\beta_{max}}{f}$$

Where N (=24) is the number of correctors, we get

$$f = N \cdot \frac{1}{4\pi}\frac{\beta_{max}}{\Delta\nu} = (24)\cdot\frac{1}{4\pi}\frac{(20)}{(.1)} = 380\,\mathrm{m}$$

At the highest momentum, this corresponds to about 0.08 T-m/m. The slew rate specification of 0.01/mm at all fields gives a slew rate spec of 8 T-m/m/s.

Skew Quadrupoles

The current skew quadrupoles are sufficient. The text of TM-0405 and the table of strengths disagree. We adopt the stronger of the two, the value from the text of 0.008 T-m/m. We take the same relative slew rate as the for the normal trim quadrupoles and ask for 0.8 T-m/m/s.

Sextupoles

The existing sextupole system is sufficient.

The 12 current horizontal sextupoles have a transfer constant of $14.9?10^{-3}$ T-m/m^2/A each and a maximum current of 100 A, for a total integrated B" of 17.8 T-m/m^2. To match that with 24 packages, the individual magnets need to produce B"L = 0.75 T-m/m^2.

The 9 current vertical sextupoles have a transfer constant of $37.5?10^{-3}$ T-m/m^2/A and a maximum current of 100 A, for a total integrated B" of 33.8 T-m/m^2. To match that with 24 packages, the individual magnets need to produce B"L = 1.4 T-m/m^2.

The design of the new system is controlled by the vertical sextupoles at 1.4 T-m/m^2. To match the fractional slew rate of the trim dipoles, we ask for 80 T-m/m^2/A.

Aperture

The existing corrector packages attach around the standard 3.5" (90 mm) outer diameter beam pipe. If significantly simplifies the design and reduces the cost, we could consider going down to a custom beam pipe as small as 2.5" (64 mm) outer diameter.

The good field region is a circle of diameter 50 mm. Within that region we will aim to keep the field uniform to 0.5%, though 1.0% is probably sufficient.

Power supplies

The expected mode of operation is for each trim dipole and trim quadrupole to have its own power supply. Ideally the dipole and quadrupole elements would run with the existing power supplies, which produce 50 A at 120 V or 30 A at 150 V.

Summary

The following table summarized the parameters of the proposed corrector system:

Type	Max. Field (B,B',B")L	Max. Slew Rate
Horizontal Trim	0.009 T-m	0.5 T-m/s
Vertical Trim	0.015 T-m	0.8 T-m/s
Quadrupole	0.08 T-m/m	8 T-m/m/s
Skew Quadrupole	0.008 T-m/m	0.8 T-m/s
Sextupole	1.41 T-m/m^2	80 T-m/m^2/s

Table 1